PART II

FARM SCALE MODELING USING THE AGRICULTURAL POLICY ENVIRONMENTAL EXTENDER (APEX)

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INTRODUCTION

Description of Study

The objective of this portion of the Lake Aquilla watershed study is to quantify (in relative terms) the erosion reduction that can be expected from the installation of a combination of best management practices on a representative farm **(Figure 1)**.

A farm scale model (APEX) was used to simulate runoff and erosion on the selected farm, which is located in subbasin number 55 (PART I – SWAT modeling) in the northeast portion of the Aquilla watershed. Existing conservation practices, or BMP's, are not adequate to control all active erosion occurring on the farm **(Figures 2 & 3)**.

Personnel from the local Natural Resources Conservation Service (NRCS) office worked in concert with the land user to develop a plan for the installation of additional BMP's to address this erosion. The planned practices include additional terracing, grassed waterways, vegetative filter strips, and shallow water areas.

The sample farm is approximately 94 acres in size. Only about 83 acres of this area was modeled, because some areas of uncontrolled drainage that flow through the farm were excluded from the simulation. One area that occurs outside of the farm boundary was included in the simulations. This area is approximately 43 acres in size, and runoff from it flows into one of the planned shallow water areas. The total area modeled is approximately 126 acres.

Figure 1. Portion of Digital Orthophoto Quadrangle with APEX study area outlined.

This sample farm is not instrumented with sampling stations to measure actual runoff and erosion. Therefore, model results presented in this report are not calibrated or validated. Simulated runoff and erosion rates are theoretical and should be interpreted as relative, rather than absolute, values.

Figure 2. View of active erosion occurring on study farm.

Figure 3. Additional view of active erosion occurring on study farm.

The APEX Model

The Agricultural Policy/Environmental eXtender (APEX) model was developed for use in whole farm/small watershed management (Williams et al., 2000). The model was constructed to evaluate various land management strategies considering sustainability, erosion (wind, sheet, and channel), economics, water supply and quality, soil quality, plant competition, weather, and pests. Management capabilities include irrigation, drainage, furrow diking, buffer strips, terraces, waterways, fertilization, manure management, lagoons, reservoirs, crop rotation and selection, pesticide application, grazing, and tillage. Besides the farm management functions, APEX can be used in evaluating the effects of global climate/CO2 changes; designing environmentally safe, and economical landfill sites; designing biomass production systems for energy; and other spin-off applications. The model operates on a daily time step and is capable of simulating hundreds of years if necessary. Farms may be subdivided into fields, soil types, landscape positions, or any other desirable configuration.

The individual field simulation component of APEX is taken from the Environmental Policy Integrated Climate (EPIC) model. . . . The drainage area considered by EPIC is generally a field-sized area, up to 100 ha (247 acres), where weather, soils, and management systems are assumed to be homogeneous. The major components in EPIC are weather simulation, hydrology, erosion-sedimentation, nutrient cycling, pesticide fate, plant growth, soil temperature, tillage, economics, and plant environment control. Although EPIC operates on a daily time step, the optional Green and Ampt infiltration equation simulates rainfall excess rates at shorter time intervals (0.1 h). The model offers options for simulating several other processes including five PET equations, six erosion/sediment yield equations, and two peak runoff rate equations. EPIC can be used to compare management systems and their effects on nitrogen, phosphorus, pesticides and sediment. The management components that can be changed are crop rotations, tillage operations, irrigation scheduling, drainage, furrow diking, liming, grazing, tree pruning, thinning, and harvest, manure handling, and nutrient and pesticide application rates and timing.

The APEX model was developed to extend the EPIC model capabilities to whole farms and small watersheds. In addition to the EPIC functions, APEX has components for routing water, sediment, nutrients, and pesticides across complex landscapes and channel systems to the watershed outlet. APEX also has groundwater and reservoir components. A watershed can be subdivided as much as necessary to assure that each subarea is relatively homogeneous in terms of soil, land use, management, etc. The routing mechanisms provide for evaluation of interactions between subareas involving surface runoff, return flow, sediment deposition and degradation, nutrient transport, and groundwater flow. Water quality in terms of nitrogen (ammonium, nitrate, and organic), phosphorus (soluble and adsorbed/mineral and organic), and pesticides concentrations may be estimated for each subarea and at the watershed outlet. Commercial fertilizer or manure may be applied at any rate and depth on specified dates or automatically. The GLEAMS pesticide model is used to estimate pesticide fate considering runoff, leaching, sediment transport and decay. Because of routing and subdividing there is no limit on watershed size. However, a practical limit may be about 2500 km^2 (965 mi^2) because of the detailed crop/management system of APEX and because daily rainfall is distributed uniformly over the entire watershed. The major uses of APEX have been dairy manure management to maintain water quality in Erath and Hopkins Counties, TX, and a national study to assess the effectiveness of filter strips in controlling sediment and other pollutants. APEX has its own data bases for weather simulation, soils, crops, tillage, fertilizer, and pesticides.

APEX Model Application

Since measured flow and sediment data are not available for the farm, the predicted runoff from SWAT was used as a comparison to "calibrate" the APEX model. APEX inputs were adjusted until simulated runoff from the farm was approximately equal to SWAT simulated runoff from subbasin number 55. Therefore, the results should only be interpreted to represent relative differences in runoff and sediment values.

APEX does not directly utilize GIS to develop input files for the model. However, in this case some GIS information was available and this data was used to facilitate construction of the subbasin files. This was accomplished by using the SWAT/GRASS input interface to build preliminary subbasin, soil, and routing files which were then reformatted for APEX (utilizing a conversion program developed by Dr. J. R. Williams). Other input files were developed utilizing a companion program (UTIL) or a DOS editor and the values for each parameter were manually entered.

In order to compare the effects of the application of best management practices, APEX runs were developed to represent three scenarios. Case I represents the farm in its existing condition (limited terracing and grassed waterways, **Figure 8**). Case II simulates the farm having additional conservation practices installed (terracing, grassed waterways, and filter strips). Case III contains all of the BMP's in Case II, along with the addition of three shallow water areas that act as sediment basins **(Figure 9)**. The creek carrying off-site runoff that dissects the farm was not modeled in any of the scenarios.

Model parameters were selected from producer information and local NRCS input to create a management scheme that reflected actual crop rotations. One subbasin file for each scenario was developed that contained a section for each sub-area and these files were customized with values such as drainage area; distance to outlet; channel, and upland length and slope; Manning's n; "C" and "K" values; soil; and tillage operation schedules. The individual sub-areas were ordered in a flow routing sequence in these files **(Figures 12-16)**.

APEX utilizes many of the same inputs as the SWAT model. These include data for soils, climate, topography, and land use. These model inputs for the study farm are illustrated and described briefly in the following section.

Model Inputs

A 30 meter (98 feet) DEM was available from the SWAT study. The small subbasin size in this APEX study necessitated the development of more detailed topographical information. This was accomplished by using the USGS 10 foot contour map **(Figure 4)** to develop a 2 meter (6.5 feet) spatial resolution DEM **(Figure 5)**.

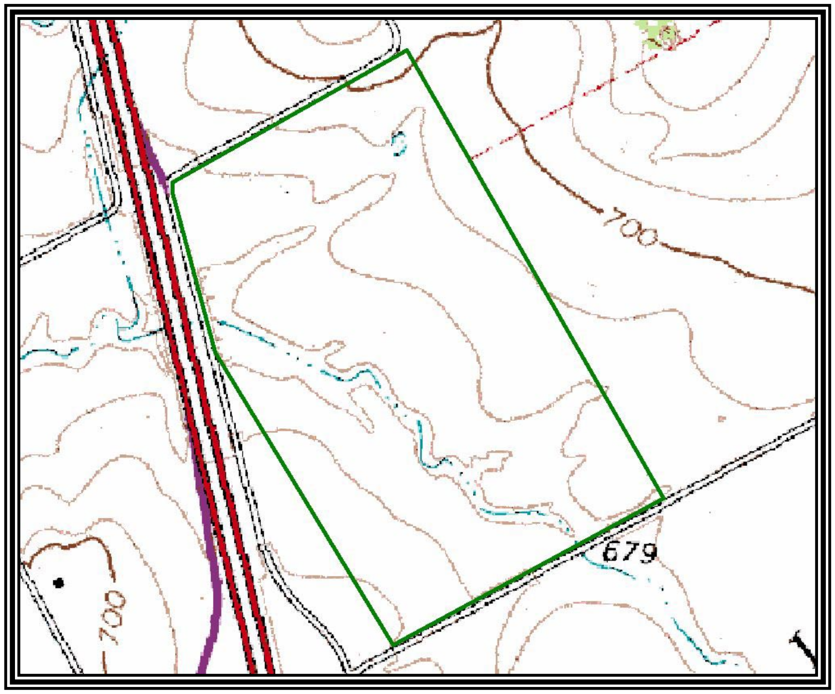

Figure 4. Portion of Digital Raster Graphic with APEX study area outlined.

Channel, routing reach, and average upland slopes were measured from this derived DEM.

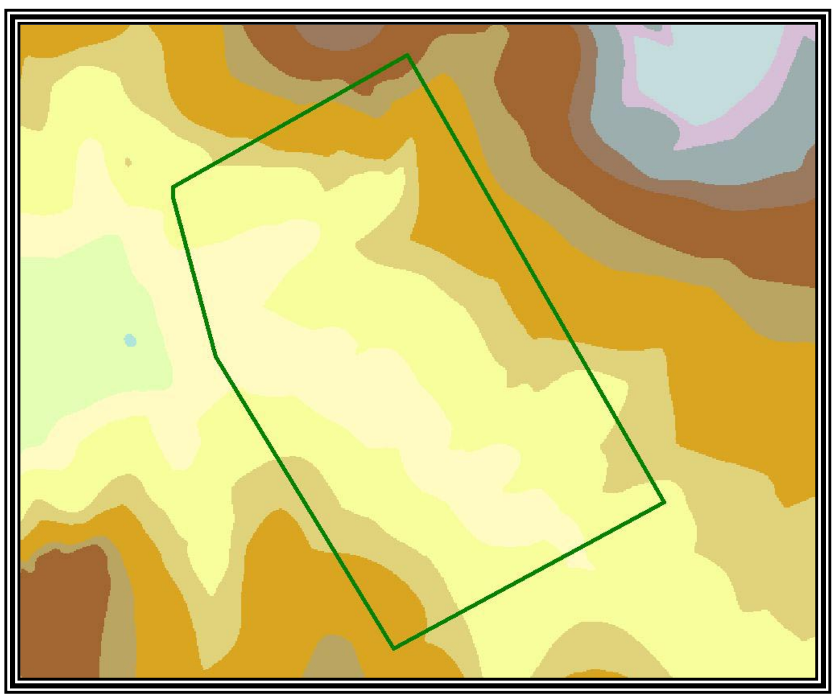

Figure 5. Digital Elevation Model for APEX study area.

The soils' names shown in **Figure 6** relate to individual files containing information relating to the physical and chemical make-up of each soil. This information is used by APEX in the simulating hydrologic and erosion processes.

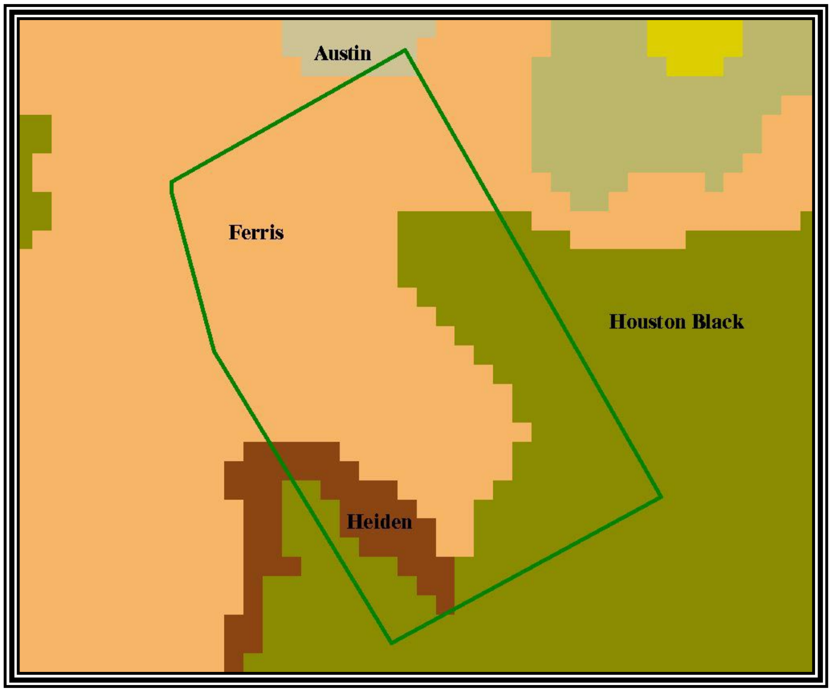

Figure 6. Soils map of APEX study area.

The land use of each subbasin **(Figure 7)** is used indirectly by APEX. In this case, all of the cropland was modeled with the same management and tillage schedules. The cropland is farmed with a four year rotation of corn, corn, wheat, and grain sorghum. Wildlife land is basically treated as rangeland.

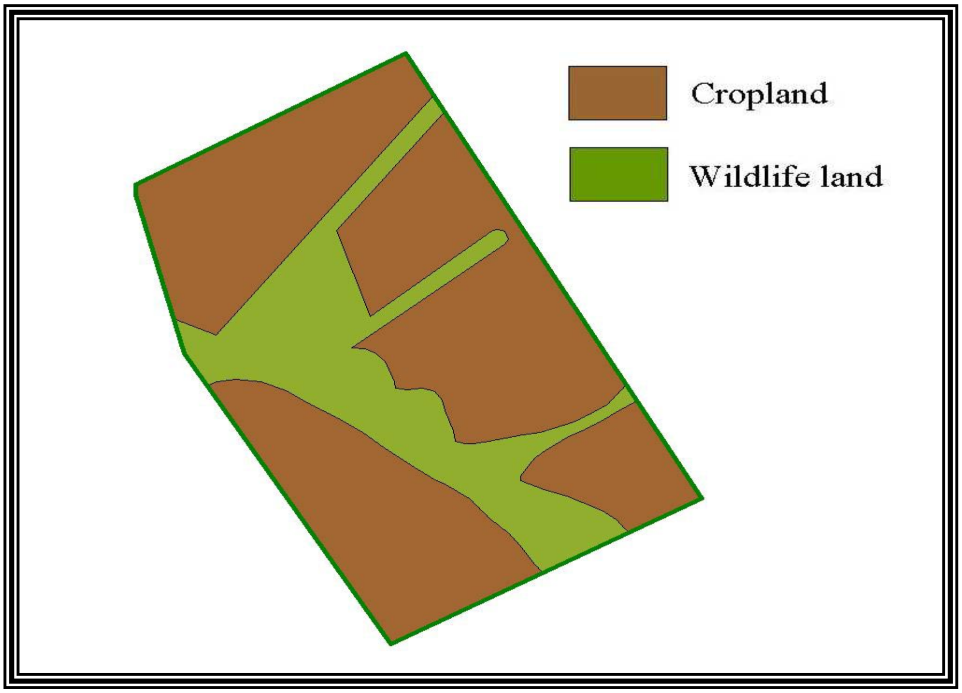

Figure 7. Current land use of APEX study area.

Climatic information for this simulation is in the form of an ASCII "flat" file. It contained precipitation and temperature data from the Hillsboro climatic station.

Modeling Scenarios

Case I represents the study farm under existing conditions. BMP's modeled in this case include six terraces and two grassed waterways as shown in **Figure 8.**

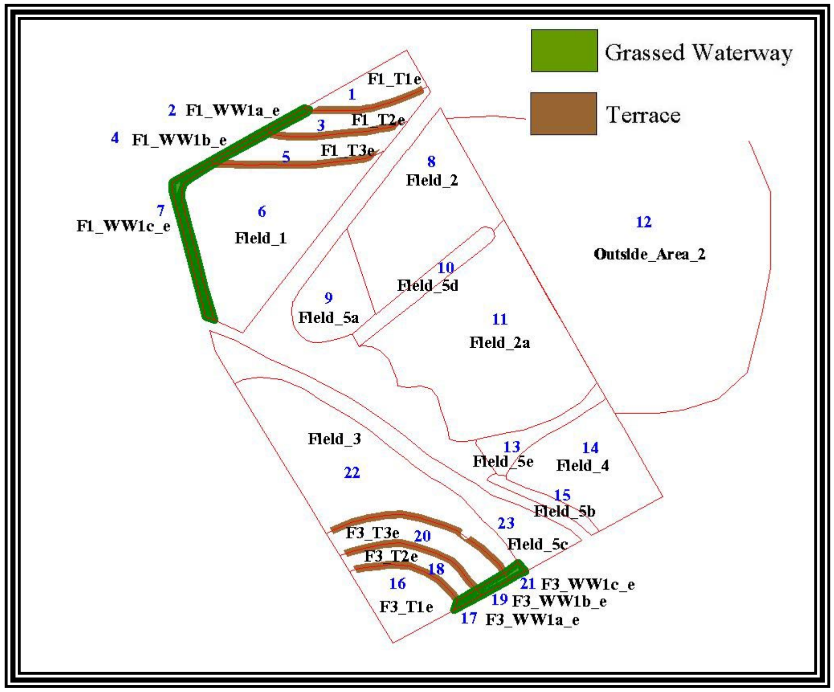

Figure 8. Case I - Best Management Practices.

Case II assumes the installation of all of the planned BMP's with the exception of the three shallow water areas. This adds eighteen terraces, two additional grassed waterways, and three vegetative filter strip areas.

Case III simulation includes all the practices in Case II and the three shallow water areas.

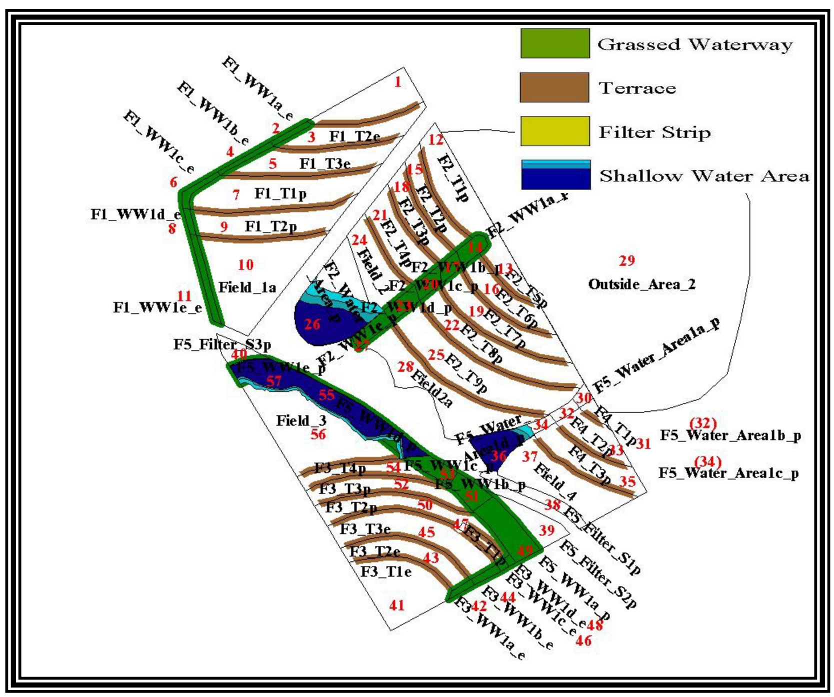

Figure 9. Case III - Best Management Practices.

Best Management Practices

The best management practices that were simulated by modeling were applied in a total resource management system. Terraces, grassed waterways, contour farming, conservation cropping systems, etc. are designed to work in concert with each other. Each complements the other. The only effort made to separate the effect of an individual conservation practice was the exclusion of shallow water areas (in Case II) from all planned BMP's.

Farm plans may be developed by individual cooperators with the assistance of personnel from various agencies such as the Natural Resources Conservation Service, the Texas State Soil and Water Conservation Board, Conservation Districts, Texas A&M Agricultural Extension Service, and others. These plans can be tailored to meet the needs of the individual farms and contain practices such as those described in this section.

Vegetative Buffers

Best described as strips or small areas of land in permanent vegetation, conservation buffers help control potential pollutants and manage other environmental concerns. Filter strips, field borders, grassed waterways, field windbreaks, shelter-belts, contour grass strips, and riparian (streamside) buffers are all examples of conservation buffers.

Conservation buffers can be used along streams and around lakes or wetlands. They can also be installed at field edges or within fields. Buffers are most effective if they are planned as part of a comprehensive conservation system. To maximize their effectiveness buffers should be combined with other proven conservation practices, such as conservation tillage, nutrient management, and integrated pest management.

Buffers slow water runoff, trap sediment, and enhance water infiltration in the buffer itself. They also trap fertilizers, pesticides, bacteria, pathogens, and heavy metals, minimizing the chances of these potential pollutants reaching surface water and ground water sources. Buffers also trap snow and reduce blowing soil in areas with strong winds. They protect livestock from harsh weather, offer a natural habitat for wildlife, and improve fish habitat.

Contour Farming and Terraces

Physical modification of field slopes and grades, or farming direction changes represent BMP's which reduce soil erosion, water runoff, and associated nutrient and chemical loss. On hilly fields, contour farming or planting crops in rows across the slope reduces losses through less soil erosion and water runoff.

Terraces are constructed to shorten the length of slopes and reduce soil erosion. They are defined as an earth embankment, a channel, or a combination ridge and channel constructed across the slope.

Grassed Waterways

A grassed waterway is a natural or constructed channel that is shaped or graded to required dimensions, and planted in suitable vegetation for the stable conveyance of runoff.

Its purpose is to convey runoff from terraces, diversions, or other water concentrations without causing erosion or flooding and to improve water quality.

This practice applies to all sites where added capacity, vegetative protection, or both are required to control erosion resulting from concentrated runoff and where such control can be achieved by using this practice alone or combined with other conservation practices. This practice is not applicable where its construction would destroy important woody wildlife cover and the present watercourse is not seriously eroding.

Shallow Water Areas (Sediment Basins)

The shallow water areas planned for this study farm are similar to sediment basins. Much of the terraced area of the farm will drain into these areas, and the primary release will be through a pipe outlet. Large flows will be allowed to exit via an emergency spillway.

A sediment basin is constructed to collect and store debris or sediment. Its purpose is to preserve the capacity of reservoirs, ditches, canals, diversion, waterways, and streams. It also prevents undesirable deposition on bottom lands and developed areas. A sediment basin reduces or abates pollution by providing basins for deposition and storage of silt, sand, gravel, stone, agricultural wastes, and other detritus.

METHODOLOGY

Subbasin Delineation

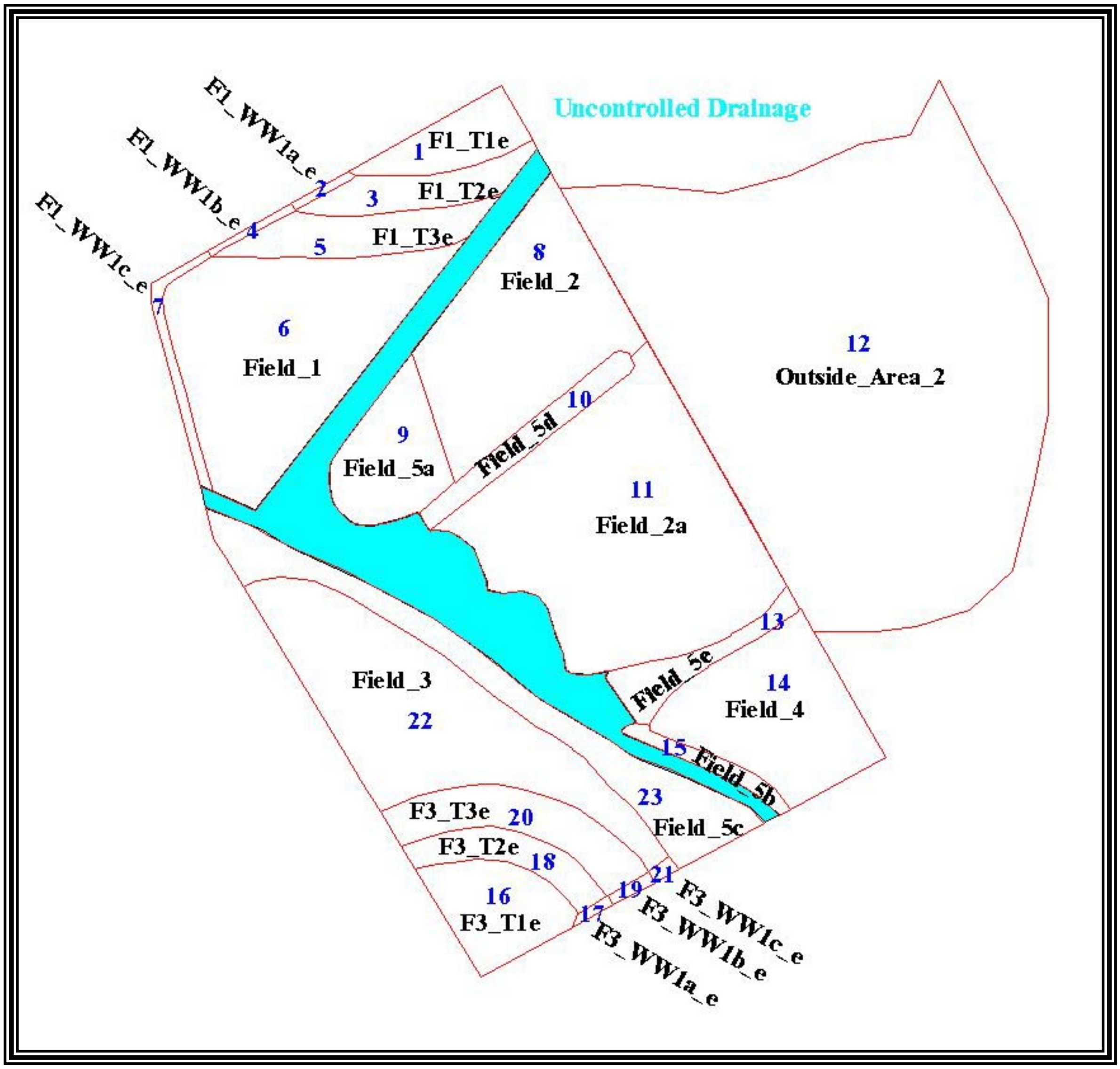

Figure 10. Case I subbasin delineation.

Case I APEX simulations were performed for 23 subbasins as illustrated in **Figure 10**. These subbasins were delineated so that each area represents a fairly homogenous area of management and soil behavioral groups. One subbasin (#12) occurs outside of the study farm boundary, but this subbasin is included in the simulations since it drains through the farm on its way to the creek. The farm is dissected into three portions by larger uncontrolled drainage areas that were not simulated.

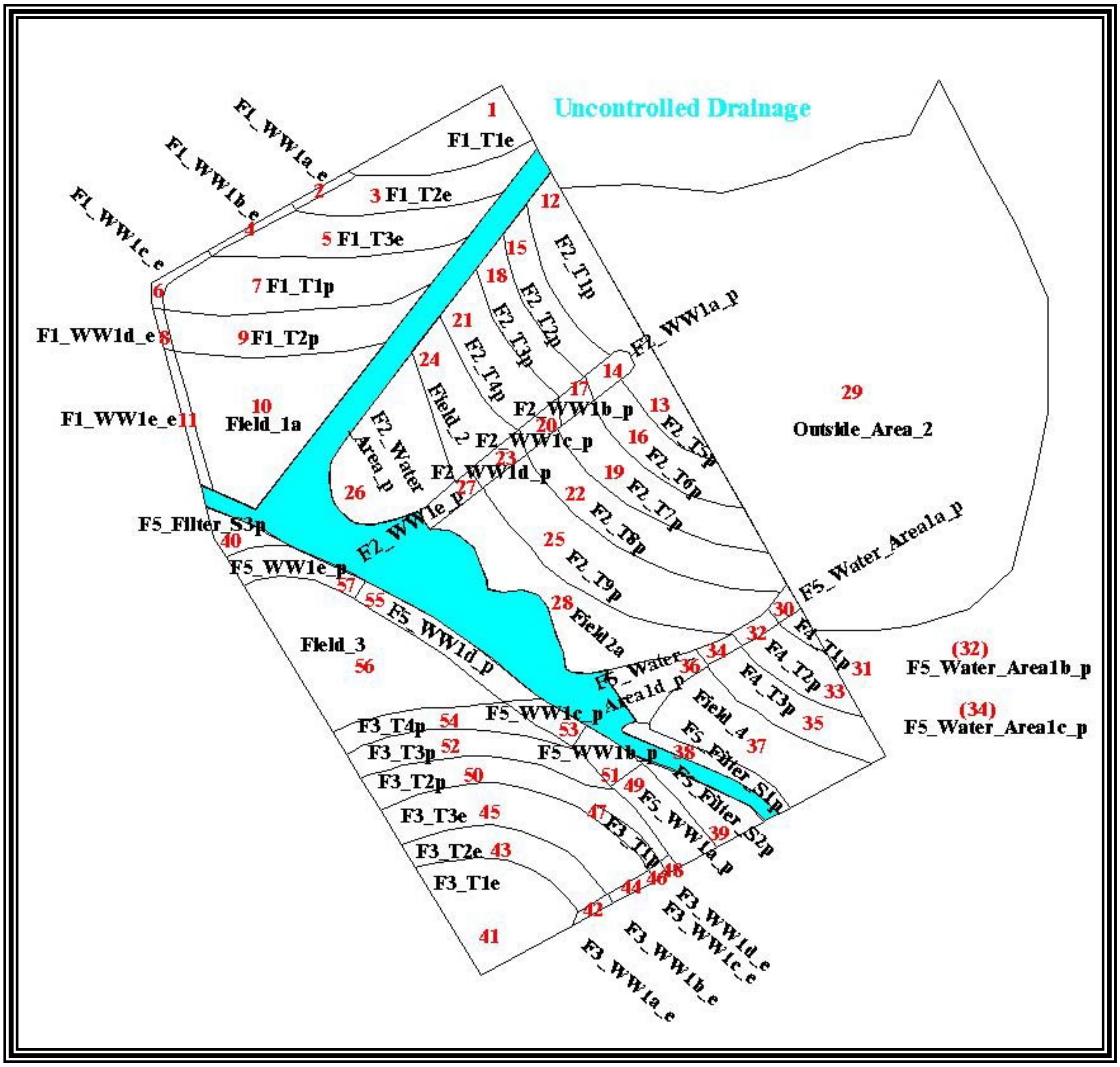

Figure 11. Cases II and III subbasin delineation.

As in Case I, uncontrolled outside drainage areas that were not modeled dissect the farm. For Case II and III simulations, 57 subbasins were needed to accurately represent installation of BMP's **(Figure 11)**. The same outside subbasin (#29) is included in the simulation.

Flow Routing

Figures 12 – 16 show the flow routing for the different modeling simulations.

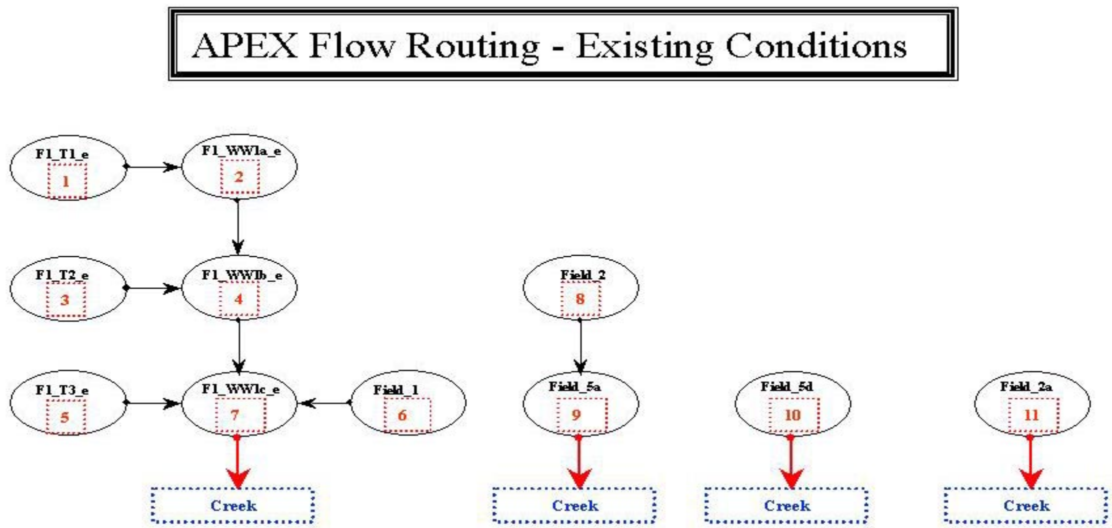

Figure 12. Case I flow routing diagram (partial).

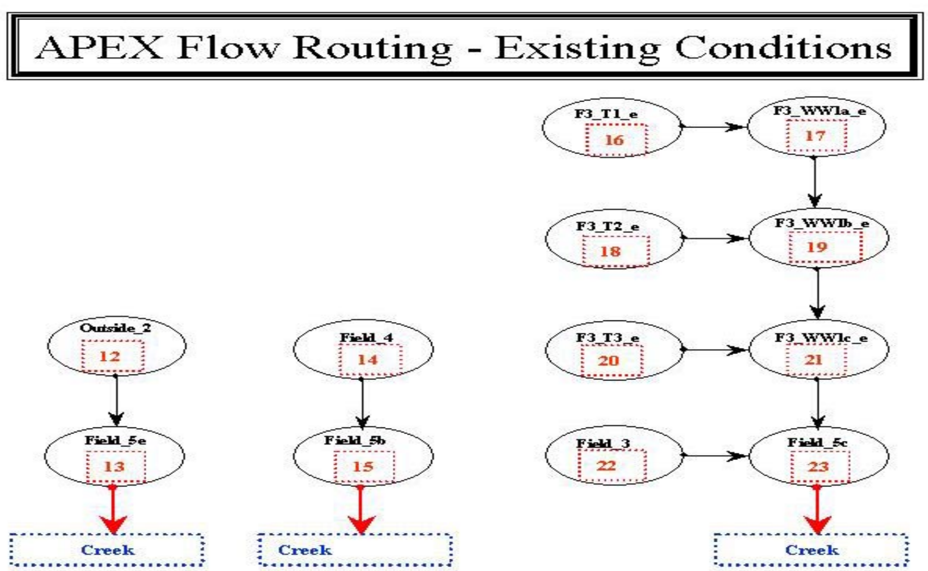

Figure 13. Case I flow routing diagram (partial).

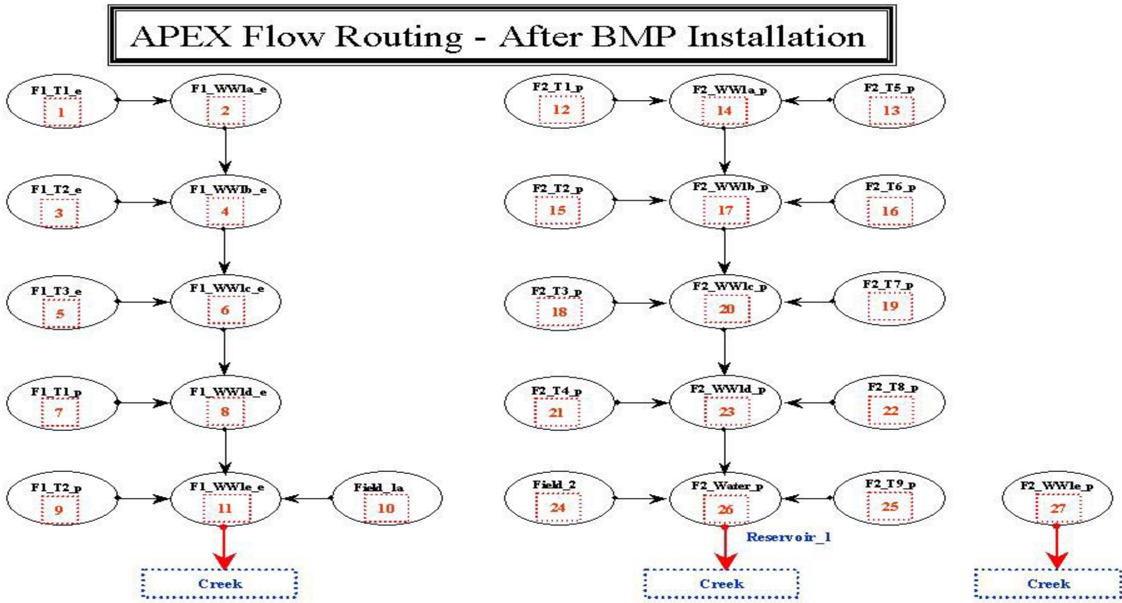

Figure 14. Case III flow routing diagram (partial).

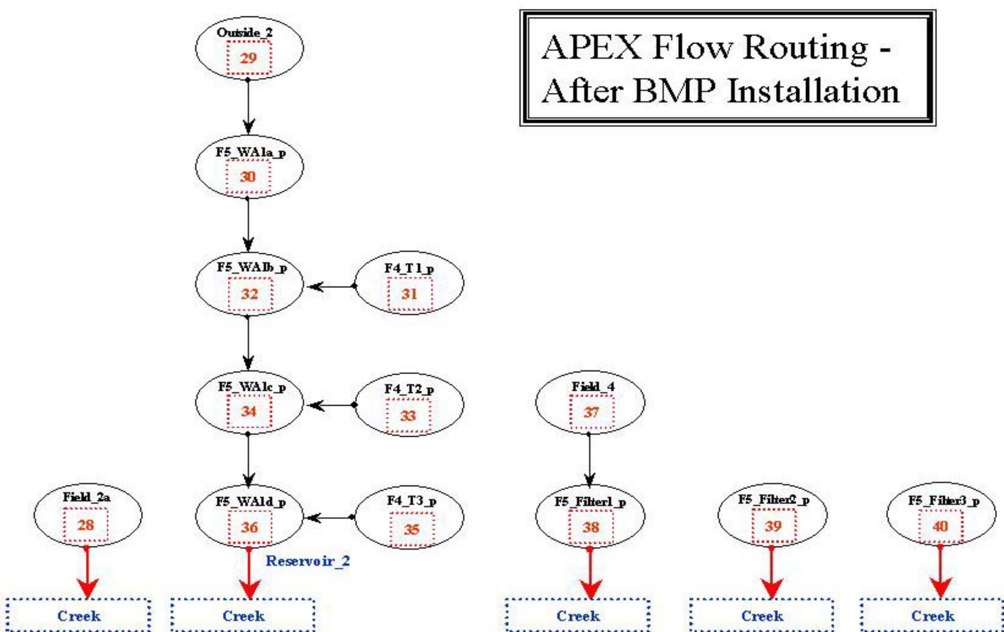

Figure 15. Case III flow routing diagram (partial).

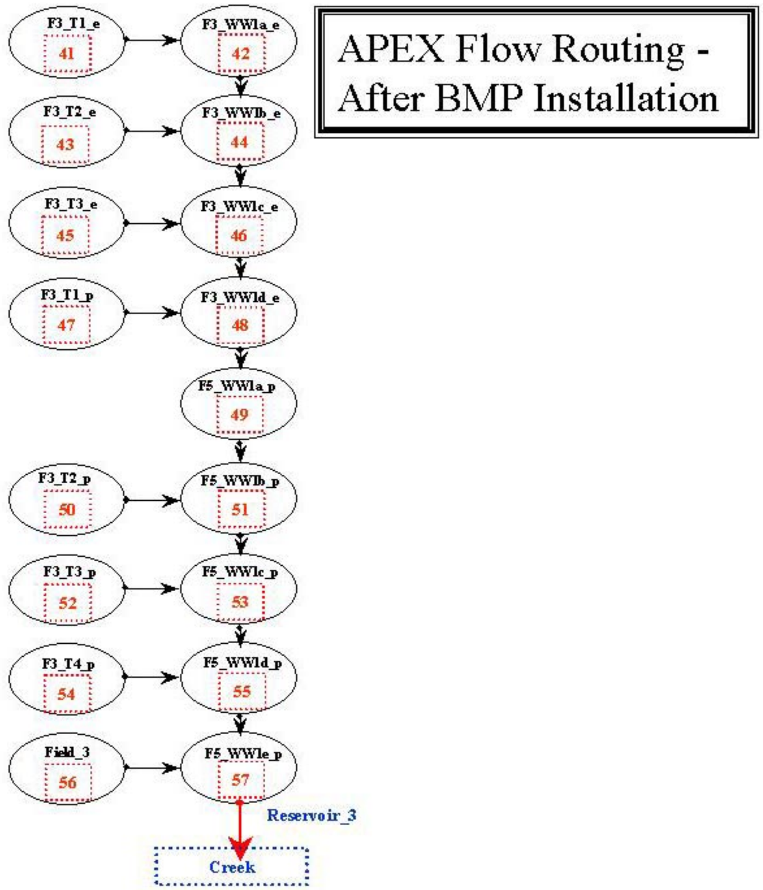

Figure 16. Case III flow routing diagram (partial).

Figures 12 and 13 represent the flow paths for runoff from the farm under existing conditions.

Figures 14, 15, and 16 show the flow routing for the study area after the installation of all proposed BMP's. These flow diagrams are much more involved than the existing conditions since some of the initial subbasins were further divided to represent new terraces, waterways, etc.

Model Parameters

<u>APEX Main Files</u>

The APEX model runs were for a period of 51 years (1950 through 2000). Actual daily precipitation and temperatures (maximum and minimum) were obtained from the Hillsboro climatic station. Other climatic values such as solar radiation, wind speed, relative humidity, etc. were generated from statistics from this same weather station.

The Hargreaves Potential Evapotranspiration Equation was specified for potential ET calculations.

The runoff was estimated by the USDA-NRCS curve number method. Peak rate runoff values were estimated using SCS (now NRCS) Rainfall Distribution II. The peak runoff rate-rainfall energy adjustment factor was set to 1.5 (this factor provides a means for fine tuning the energy factor used in estimating water erosion). The runoff curve number was allowed to vary on a daily basis by the soil moisture index (the parameter for the amount of variance [SCS Curve Number Index Coefficient] in the parm file was set to a value of 2.0).

The latitude of the watershed is 32.06 decimal degrees and the average elevation is approximately 702 feet(214 meters).

The Modified USLE water erosion equation was specified to drive the model's estimation of soil profile degradation. Wind erosion was not considered.

<u>APEX Sub Files</u>

Manning's "n" (roughness coefficient) values were set to 0.15 for upland areas and 0.05 for most of the flow routing reaches.

The conservation practice factor "P", which is the ratio of soil loss for a given practice to that for up and down the slope farming was also held constant at 1.0 (no adjustment). This was done so as not to "double account" for the benefits of every installed practice. These benefits were already accounted for by the delineation of subbasins for every installed, and proposed, BMP. Slope, slope lengths, channel lengths, etc. were all adjusted to account for the changes in runoff patterns as influenced by their installation.

Where filter strips were installed, a factor of 0.65 was assumed to represent the overall hydraulic effectiveness of each strip. This factor does not represent sediment or nutrient trapping efficiency, rather it represents the variability of the land surface which causes some areas of the buffer to receive more runoff than other areas.

Channel dimensions were specified for all grassed waterways and existing gullies on the study farm. All waterways were assumed to have the same channel dimensions unless there is active degradation in the channel section (Case I only). If this is the case, the waterway section was assumed to have the same dimensions as those assumed for gullies. For waterways performing as designed, these dimensions are: top width - 40 feet (12 meters), bottom width – 28 feet (8.5 meters), and depth 1.5 feet (0.45 meters). For gullies, or gullied sections of waterways (Case I), the assumed dimensions are: top width - 10 feet (3 meters), bottom width - 3.3 feet (1 meter), depth - 2.5 feet (0.75 meters), Manning's "n" – 0.04.

The Modified USLE equation also uses "C" and "K" factors for channels defined in the sub file. "C" is a cover and management factor and is defined as the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow. The channel USLE "C" factors for the routing reaches were allowed to vary by land use. The "C" factor for a four year rotation of corn, corn, wheat, and grain sorghum was assumed to be 0.4. Grassed waterways and filter strips had a "C" factor of 0.01, while areas classified as wildlife land had this factor at 0.10.

The "K" factor is the soil erodibility factor and is the average soil loss in tons/acre per unit of erosion index for a particular soil in cultivated continuous fallow with an arbitrarily selected slope length of 73 feet and slope steepness of 9 percent. The channel USLE "K" factor for the routing reaches were constant at 0.32 since the three main soils in the farm (Houston Black, Heiden, and Ferris) are very similar.

Case III added three shallow water areas to complete the planned BMP's. The following information was input in the reservoir section for each of these areas:

(A) total reservoir surface area at emergency spillway elevation – hectares,
(B) runoff volume from reservoir catchment area at emergency spillway elevation – watershed millimeters,
(C) total reservoir surface area at principal spillway elevation - hectares,
(D) runoff volume from reservoir catchment area at principal spillway elevation – watershed millimeters,
(E) initial reservoir volume – watershed millimeters,
(F) average principal spillway release rate – mm/hr,
(G) initial sediment concentration in reservoir – ppm,
(H) normal sediment concentration in reservoir – ppm,
(I) hydraulic conductivity of reservoir bottom – mm/hr, and
(J) time required to return to normal sediment concentration – days.

This information was estimated from the GIS coverage of the study farm. Values for the three shallow water areas are shown in **Table 1.**

Table 1. Reservoir Information.

	Reservoir 1	***Reservoir 2***	***Reservoir 3***
A	0.7530 (1.86 ac.)	0.3720 (0.92 ac.)	1.0710 (2.65 ac.)
B	72.060 (2.84 in.)	23.675 (0.93 in.)	50.9300 (2.01 in.)
C	0.5870 (1.45 ac.)	0.3430 (0.85 ac.)	0.9860 (2.44 ac.)
D	47.954 (1.89 in.)	19.157 (0.75 in.)	39.073 (1.54 in.)
E	10.000 (0.39 in.)	10.000 (0.39 in.)	10.000 (0.39 in.)
F	2.8500 (0.112 in/hr)	1.6000 (0.063 in/hr)	3.2300 (0.127 in/hr)
G	500.00	500.00	500.00
H	350.00	350.00	350.00
I	0.0800 (0.003 in/hr)	0.0800 (0.003 in/hr)	0.0800 (0.003 in/hr)
J	30.000	30.000	30.000

RESULTS

The results for the 51 year simulation (1950-2000) indicated that both water and sediment yield were affected by application of BMP's.

The annual water yield from the study area for each case is shown in **Figure 17.** The average annual water yield for Case I (existing conditions) was 8.5 watershed inches (215 millimeters). This compares favorably with the runoff as modeled by SWAT (207 mm in subbasin 55). For Case II, implementing all planned BMP's with the exception of the shallow water areas (ponds) produced an average annual runoff of 7.7 watershed inches (196 millimeters). Adding the shallow water areas to the planned BMP's (Case III) resulted in an average runoff of 6.0 watershed inches (151 millimeters).

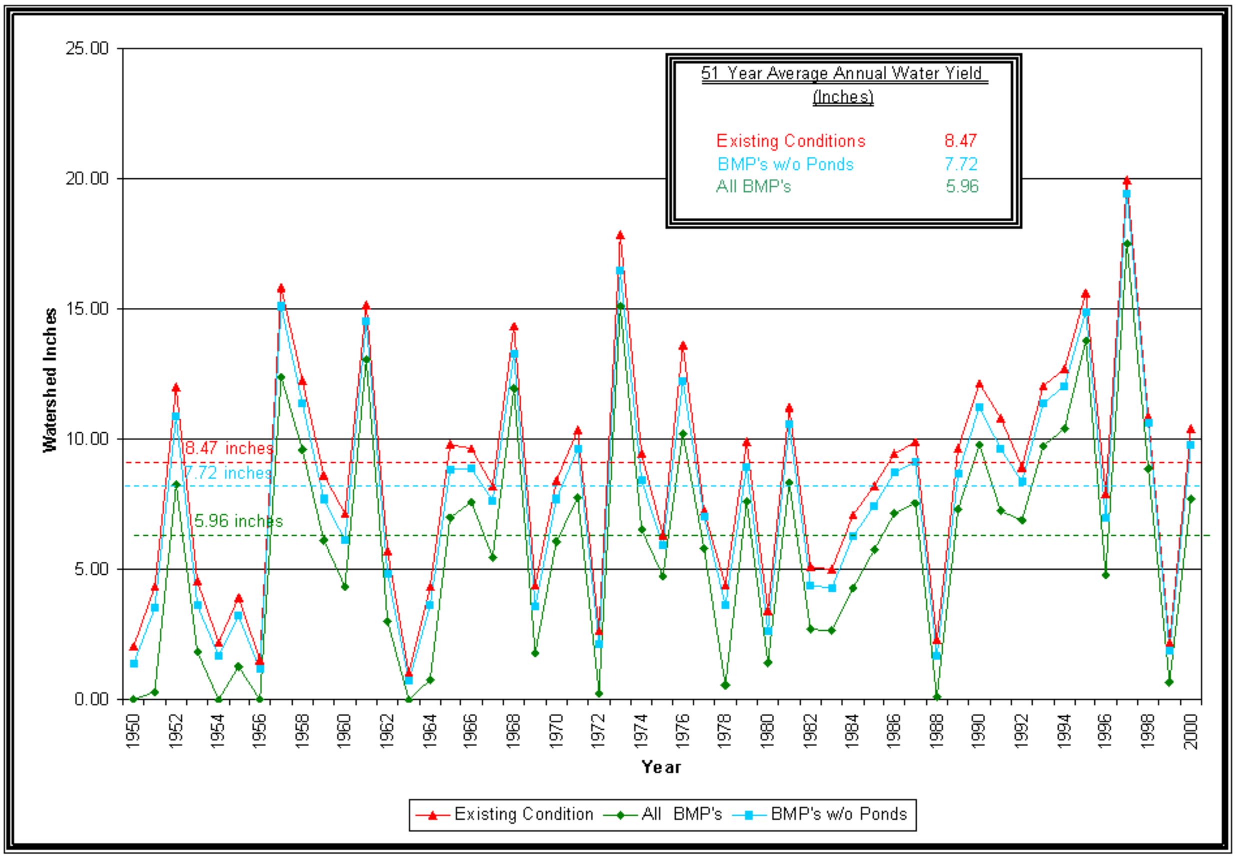

Figure 17. Annual simulated water yield for Cases I, II, & III, 1950 – 2000.

Simulated annual sediment yield is shown in **Figure 18.** Average annual sediment yield for Case I is 6.85 tons/acre (15.36 metric tons/hectare), for Case II is 3.06 tons/acre (6.87 metric tons/hectare), and for Case III is 0.28 tons/acre (0.63 metric tons/hectare). A summary of modeling results with relative percent reduction in water and sediment yields for each scenario is shown in **Table 2.**

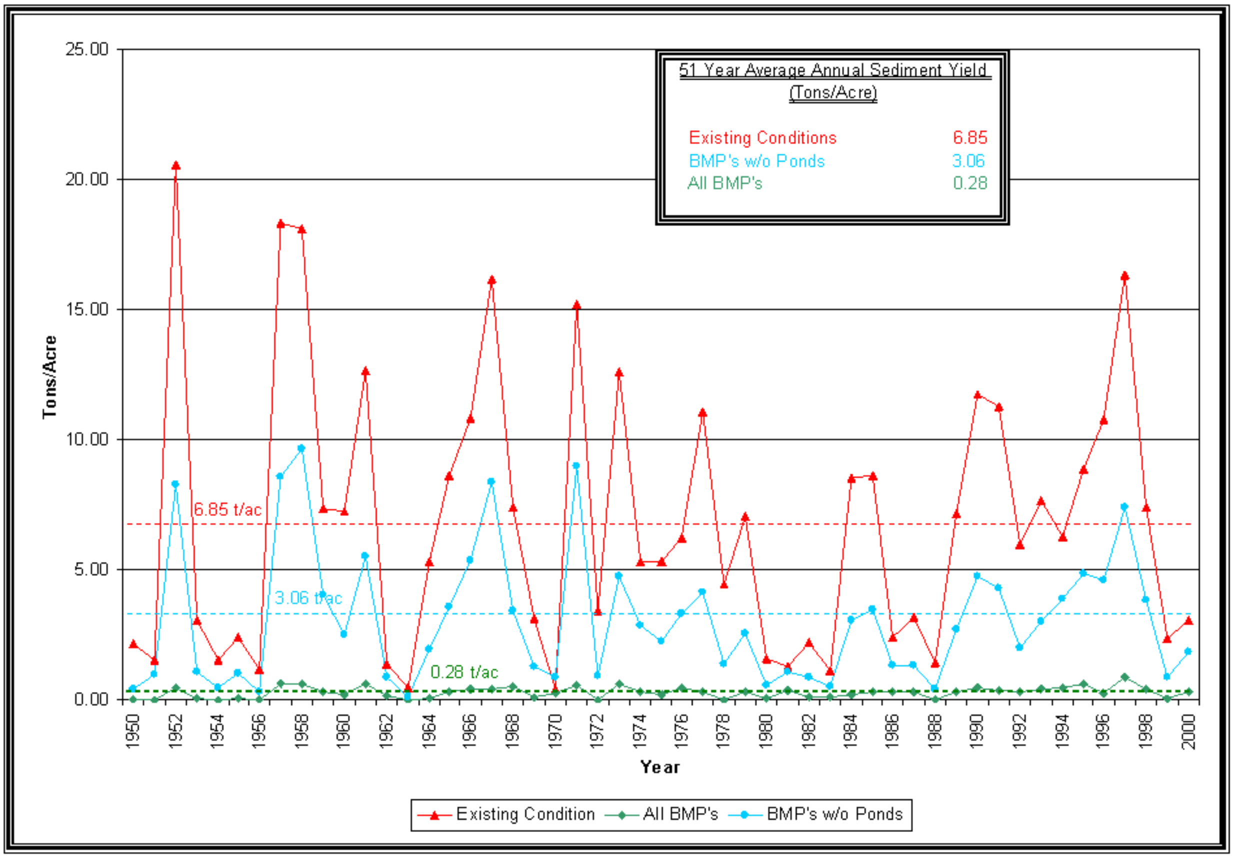

Figure 18. Simulated annual sediment yield for Cases I, II, & III, 1950 – 2000.

Table 2. Results of simulations.

	Case I Existing	***Case II BMP's w/o Ponds***	***Case III All BMP's***
Water Yield (acre-feet)	4,524	4,125	3,185
Percent Reduction (from existing)		8.8	29.6
Sediment Yield (tons)	43,907	19,630	1,810
Sediment Yield (acre-feet)	40.4	18.1	1.7
Percent Reduction (from existing)		55.3	95.8

It is important to remember that these model results assume that the effectiveness of all BMP's remains static over the modeling period. APEX does not account for the loss of capacity in terraces, waterways, filter strips, or reservoirs that is due to sediment accumulation. BMP's will also lose effectiveness if adequate maintenance is not performed on a periodic basis.

LITERATURE CITED

Williams, J.R., J.G. Arnold, R. Srinivasan. 2000. The APEX Model. Texas Agricultural Experiment Station, BRC Report No. 00-06, October 2000.